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TECHNOLOGY FOR CONDENSATE RETURN LINES

by

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An investigation was conducted by the Naval Facilities Engineering Service Center (NFESC) to determine current and emerging technology for cost-effective, durable materials for condensate return lines associated with district piping systems for central steam distribution on Navy shore facilities. The distributed steam may be used for building heating, cooking, ships supply, and other direct-use processes. This investigation sought to identify materials and specific technology to improve the reliability and maintainability of these condensate return lines. The investigation included literature searches for technology associated with all types of piping materials including piping material and piping processes not generally associated with steam condensate return. The search for a durable material to replace existing materials used for condensate return piping was unsuccessful. Provided that returning condensate to the boiler is economical based on site factors, improvements to the reliability and maintainability of condensate return lines can be accomplished through stricter adherence to existing installation specifications and operating procedures. Alternatively, the reliability and maintainability of a steam system may be improved by converting all or part of the heating load over to a hydronic system. The economics of this conversion would likely pay only for those facilities considering system replacement or system expansion.

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INTRODUCTION

An investigation was conducted by the Naval Facilities Engineering Service Center (NFESC) to determine current and emerging technology for cost-effective, durable materials for condensate return lines associated with district piping systems for central steam distribution on Navy shore facilities. The distributed steam may be used for building heating, cooking, ships supply, and other direct-use processes. This investigation sought to identify specific technology to improve the reliability and maintainability of the condensate return lines.

Upon giving up its latent heat content, steam condenses to water and the condensate is available for return to the boiler via the condensate return piping. At many Navy activities, condensate is not returned to the boiler because it is either nonrecoverable process steam or because returning the condensate would be a cost penalty. An example of the latter is when strict clean steam requirements for ship use at port dictate discarding condensate from other terminal units that do not meet condensate quality standards. Where condensate return is viable, contamination and loss of the condensate are the engineering issues to which this investigation sought solutions.

The investigation included literature searches for technology associated with all types of piping materials including piping materials and piping processes not generally associated with steam condensate return. Personal contacts were made with individuals ranging from operators to piping manufacturers. Comments from members of the Department of Defense (DOD) Committee on Heat and Cooling Exterior Distribution Systems had a strong influence on the findings.

In the absence of new technology applicable to improving the durability of condensate return line piping and based on recommendations to transition away from central steam heating, this investigation was expanded to briefly review the issue associated with retrofitting steam to hydronic heating (and cooling) systems.

BACKGROUND

The Navy is actively looking to reduce operating costs at shore facilities to meet diminishing operating budgets. A part of the cost reduction is mandated by the Energy Policy Act of 1992 dealing with the conservation and efficient use of energy. In the Act, Section 152 addresses the Federal Energy Management Program (FEMP) and requires, by the year 2005, installation of all energy and water conservation measures with payback periods of 10 years in Federal buildings to the maximum extent practicable (Ref 1). Conservation of boiler water through effective condensate return can contribute to meeting this energy objective.

Steam heating systems are divided and classified as low pressure or high pressure. The low pressure steam system is one with a boiler operating pressure less than 15 psig. High pressure steam is defined as any system with pressures above 15 psig.

A steam distribution piping system can be either a single pipe design or a two pipe design. The single pipe system, as the name implies, has one pipe that carries both supply steam and

return condensate between the boiler and the load. The counter flow within the pipe is accommodated by sloping the pipe to provide gravity return of the condensate to the boiler. The simplicity of the design lends itself to application in small buildings. However, for district heating (single boiler plant with multiple outlying buildings) a two pipe steam heating system is required.

The two pipe steam heating system has a supply pipe to deliver the steam and a return pipe to carry condensate back to the boiler from each terminal unit. The return piping in the two pipe design can be either gravity return or pumped return. As mentioned before, in those cases where condensate is not available or not economical for return, the return pipe is typically omitted and condensate is dumped to the sewer.

The are several acceptable practices for installation of district heat piping. System piping can be installed in tunnels, in shallow concrete trenches, in deep buried trenches, in direct buried trenches, or aboveground. Obviously, aboveground installation may not be pretty to look at, but it serves the purpose of reducing installation and maintenance costs. Installation guidelines are available from several sources, including Military Handbooks, Naval Facility Engineering Command Guide Specifications, and commercially, from sources such as the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE).

In order to preserve the insulation used on the steam carrier pipe and the condensate carrier pipe, the insulated carrier pipe is protected inside a conduit pipe. In some cases, the conduit houses a single carrier pipe while in other cases, two carrier pipes can be protected in a single conduit. The ASHRAE Systems and Equipment Handbook is suggested as a reference on possible arrangement for conduit systems (Ref 2).

FINDINGS

The investigation process surveyed and reviewed of a variety of information sources to determine current and emerging technology for cost-effective, durable materials for condensate return lines. The sources of information included:

1. Participants and documentation from recent DOD condensate return line projects.

2. Personnel involved with district heating and condensate return projects including Public Works Centers (PWC) and Engineering Field Divisions (EFD) utilities personnel at selected Navy bases.

3. Personnel in RDT&E groups at companies identified as having possible technological advances.

4. Sales literature.

5. Technical publications (a listing of titles reviewed during the literature search is included in Appendix A).

No site survey or testing was performed in conjunction with this investigation. Utility personnel and underground district heating engineers were relied on for their field experience. This investigation focused primarily on replacement piping and piping repair techniques as a means to extend service life thereby reducing condensate loss, and to reduce maintenance requirements thereby minimizing condensate contamination. For screening durable materials for condensate return piping, a 250°F live steam exposure condition was used in this investigation as a minimum criteria.

Site Classification

For purposes of underground installation, restrictions on conduit system type are classified by the underground water conditions at the project site. Classes A, B, C, or D correspond to underground water conditions ranging from severe to mild, respectively, as described in Table 1.

The site conditions described in Table 1 for underground distribution systems have a significant effect on the function and efficiency of the distribution piping. Class A and Class B site conditions deserve special attention because of the possibility of conductive heat losses and piping system damage caused by wet insulation. Severe site conditions may necessitate aboveground installation. Though aboveground installations are not uncommon, they are not favored because aboveground distribution piping is unsightly.

Table 1
Site Classification

Site Classification	Water Table	Surface Water
Class A (Severe)	Frequently above the bottom of the system.	Expected to accumulate or remain in the surrounding soil for long periods.
Class B (Bad)	Occasionally above the bottom of the system.	Expected to accumulate or remain in the surrounding soil for short periods.
Class C (Moderate)	Never above the bottom of the system.	Expected to accumulate or remain in the surrounding soil for short periods.
Class D (Mild)	Never above the bottom of the system.	Not expected to accumulate or remain in the surrounding soil.

DOD Approved Vendors

The Naval Facilities Engineering Command Guide Specification (NFGS) 02694F on the Exterior Underground Heat Distribution System (Ref 3) covers requirements for contractor designing and providing exterior buried factory-prefabricated preinsulated steam piping and condensate piping for Class A and Class B ground water conditions. Installation of new or

modification to existing steam distribution piping at Class A or Class B sites is restricted to those piping systems for which a Federal Agency Approved Brochure has been issued. Military Handbook MIL-HDBK-1003/8A on Exterior Distribution of Steam, High Temperature Water, Chilled Water, Natural Gas, and Compressed Air (Ref 4) lists the ten system suppliers issued Federal Agency Letters of Acceptability required in NFGS-02694F.

This strict limitation is necessary to ensure uniformity in performance. Oversight and control of the approved system suppliers fall within the charter of the DOD Committee on Heating and Cooling Exterior Distribution Systems. The charter goal is "to assure that reliable heating and cooling exterior distribution systems are available for use by the participating agencies," of which the Navy is a primary member. It is also part of the Committee charter "to assure that these systems can achieve a sufficiently long life to make them economically feasible when using Government design, construction, operation and procurement criteria and constraints." The stated method to accomplish these goals is "to improve products that are currently available in the short term, and to partner with other professional groups to develop a national and/or industry standard in the long term" (Ref 5).

This interagency Committee was a primary source of information and was well acquainted with the issues associated with condensate return and related new technology. A review of the prioritized list generated by the Committee on technology topics related to underground distribution systems (Appendix B) does not show a definitive need for development in the area of condensate piping. In fact, conversations with Committee members suggest that central steam distribution is not a favored process (Ref 6). Other Navy sources confirmed this with the recommendation for conversion of central steam to high temperature hot water (HTHW) heating systems on a replacement basis. Such is the plan for the Norfolk Navy Shipyard in the conversion scheduled for the year 2005 (Ref 7).

Current Practice

The temperature and pressure rating for the condensate return piping varies by design for low pressure and high pressure steam heating systems. It is difficult to identify a maximum exposure temperature for condensate piping that is applicable in all systems. An obvious upper limit for low pressure steam systems is the saturated steam condition (15 psig at 250°F) that can result in the event of steam trap failure. This is the reason 250°F was chosen for screening the candidates for durable condensate piping. A lower temperature rating will apply to low pressure systems wherein steam trap discharge does not vent directly into the condensate pipe. These systems, designed with condensate wells, may suffer some loss of efficiency due to lost enthalpy but the condensate return condition is at a lower temperature (less than 212°F).

The condensate return temperature for high pressure steam systems is typically higher than the condensate returned from a low pressure steam system. Selection of a maximum exposure temperature for high pressure steam condensate piping would need to be based on the specific system design.

In all systems, piping, fittings, and accessories are typically specified as conforming to American National Standards Institute (ANSI) Standard B31.1 on Power Piping (Ref 8). MIL-HDBK-1003/8A further stipulates that underground prefabricated or pre-engineered systems must conform to NFGS-02694F on the Exterior Underground Heat Distribution System which includes the requirement for pre-approved system vendors.

Piping wall thickness for the steam carrier pipe is usually American Society for Testing and Materials (ASTM) A 106 Schedule 40 (Ref 9) for steel pipe sizes through 10 inches, and minimum pipe wall thickness of 0.375 inch for pipe sizes 12 inches and larger. Where steel piping is used for condensate returns, NFGS-02694F requires Schedule 80 steel piping. The Schedule 80 piping is more appropriate because the extra wall thickness over Schedule 40 steel pipe provides a margin against corrosion, increasing the service life of the piping (Ref 10).

Unpublished data from a 1991 survey conducted by the Naval Civil Engineering Laboratory (now the Naval Facilities Engineering Service Center) on Navy shore facility boilers contained some information pertaining to distribution piping and condensate return. Table 2 shows a comparison of six Marine Corps bases selected from the survey data. These sites do not have requirements for clean steam for ships at port. The intent of this table is to show general steam usage and the amount of condensate returned for cases where returning the condensate is viable.

Table 2
Selected Survey Samples for Condensate Return Systems

Location	Distribution Piping	Steam Usage	Condensate Returned
MCRD Beaufort Charleston, SC	95% Above 5% Shallow Trench	80% Heating 20% Process	25-45% @ 150-190°F
MC Combat Development Command Stafford, VA	31% Above 15% Direct Buried 44% Shallow Trench 10% Tunnel	70% Heating 10% Process 20% Losses	35% @ 180°F
MCAS Kaneohe Bay, HI	N/A	80% Heating 20% Losses	20-55% @ 100-180°F
MC Camp Pendleton Camp Pendleton, CA	5% Above 5% Shallow Trench 90% Tunnel	N/A	90% @ 280 - 300 °F
MC Camp Lejeune Camp Lejeune, NC	77% Above 23% Direct Buried	70% Heating 15% Process 15% Losses	28 - 72% @ 180°F
MCLB Albany, GA	100% Tunnel	20% Heating 80% Process	15% @ 220°F

The first observation that can be made from Table 2 is that a large portion of the distribution piping is installed aboveground or in tunnels. This would imply that direct access to the piping was possible for inspection, maintenance, and repair. Again, the focus of this investigation was to identify ways to minimize condensate loss and contamination. Yet, as in the cases of MCRD Beaufort, MC Combat Development Command, and MCAS Kaneohe where the majority of steam usage is for heating (a recoverable steam process), less than half of the steam

supplied for heating was reported as returned condensate. It is implied from the survey data that the low percentage of condensate return was due to inadequate condensate return piping. No information was available on whether or not the returned condensate was contaminated. It is assumed that the returned condensate was suitable for reuse.

The second observation made from Table 2 data is the large temperature range of the returned condensate for all systems, from a low of 100°F to the high of 300°F. As will be discussed in the following section, the ability to carry high temperature condensate is beyond the design of composite piping material. Steel piping is the only material identified in this investigation able to carry high temperature condensate.

Plastic Piping

Military Specification MIL-P-28584B: Pipe and Pipe Fittings, Glass Fiber Reinforced Plastic, Adhesive Bonded Joint Type, for Condensate Return Lines (Ref 11) covers plastic pipe and fittings made from epoxy resin and glass fiber reinforcements, together with epoxy adhesive necessary for joint assembly. The specification covers condensate return service up to 125-psi operating pressure at 250°F. Additional protection is provided in the fiber reinforced plastic (FRP) pipe design from a bore liner made of a smooth epoxy resin that protects the glass fiber reinforcement.

The primary reason for FRP pipe application in condensate return piping is to mitigate corrosion and the resultant condensate contamination. As will be discussed in the next section on boiler water treatment, condensate piping corrosion is a cause for concern and usually caused by high level of dissolved CO_2 or by the presence of oxygen. For this reason, FRP piping is a desirable alternative over steel piping.

It is reported that FRP piping has a lower installation cost over heavy wall carbon steel (Ref 12). FRP piping can be assembled without welding or heavy lifting equipment during installation and afterward during maintenance. The advertised benefits of fiberglass piping systems are:

- Economical installation
- Economical operation
- Long piping system lifetime

Despite these benefits and the MIL-P-28584B requirement for product acceptance cyclic temperature testing to 300°F using hot water, FRP pipe has a history of failure. The cause of this failure is reported as live steam exposure from failed open steam traps (Refs 13, 14). Evidence of this type of failure suggests improper installation. MIL-HDBK-1003/8A encourages the use of plastic condensate piping for underground installations but warns that steam traps shall not discharge into plastic condensate piping because live steam cannot be tolerated. Instead, steam trap condensate should run to a flash tank or well where it can be pumped back to the boiler with no harm to the plastic piping. The disadvantage to this method is the potential loss of enthalpy at

the condensate well. In addition, if the condensate is not gravity returned but must be pumped back to the boiler, the energy penalty to pump the condensate must be considered.

It has been suggested in the literature that FRP pipe failure is not strictly due to thermal stress and that limited cyclic exposure to steam does not cause failure. The failure mechanism is reported to be a combination of the thermal stress from steam exposure coupled with the occurrence of a severe water hammer concurrent with the discharge of flash steam (Ref 12). In any case, following MIL-HDBK-1003/8A recommendations for proper FRP pipe installation eliminates this failure mechanism.

Boiler Water Treatment

The Department of the Army, in Technical Note No. 86-3 on the Use of Diethylaminoethanol, Morpholine, and Cyclohexylamine for Condensate Return Line Corrosion Prevention (Ref 15) provides a discussion on the causes and treatment of condensate corrosion. The Army reports that "corrosion of return line systems is more common in installations having extensive return systems, such as central energy plants." This may be because the maintenance of distribution system piping is usually left to the pipe fitters or is otherwise orphaned because of diminished maintenance budgets. Boiler operators within the Navy tend to disown, in terms of maintenance, those parts of the system that are beyond 5 feet away from the boiler building (Ref 16). The Army has identified three factors as cause for condensate piping corrosion (Ref 15). They are:

- The presence of carbon dioxide originating from boiler makeup water alkalinity.
- The presence of oxygen entering through leaky traps, pumps, valves, and fittings or with boiler feedwater that is not deaerated and treated with sodium sulfite.
- Potable water contamination through leaks of mineralized water generally at hot water heater tubes.

Proper boiler water chemical treatment and maintenance of the distribution system to prevent leaks and contamination is a successful plan of action to ensure system longevity. The recommended pH limit for condensate in all return systems is 7.5 to 8.0. Corrosion rates increase rapidly as the pH falls below 7.5 (Ref 15). Condensate return line corrosion prevention is an important aspect of boiler water chemistry and, if not rigorously adhered to, can lead to boiler damage.

Economics

MIL-HDBK-1003/8A recommends using ASHRAE guidelines for determining the economics of returning condensate, but it reports that condensate return is preferred if it costs less than using and treating raw water for makeup (Ref 4). The factors listed in favor of condensate return are:

- High area concentration of steam usage
- Restriction on condensate disposal
- High raw water treatment costs
- Water treatment space unavailable
- High cost of raw water
- High cost of fuel for feedwater heating

Missing from this factor list is the conservation of energy and the conservation of water per the Energy Policy Act of 1992. Projects with payback periods of 10 years or less are to be considered under the FEMP.

Not returning the condensate may be more expensive when the cost of the energy in the form of sensible heat and the cost of boiler makeup rates with water treatment are considered. As an example, looking at just the heat loss at one boiler plant at MCRD Beaufort, approximately 44,600 gallons of condensate water was lost in 1990 (excluding process steam unrecoverable condensate). At the condensate return condition of 345°F at 125-psi pressure, this water loss represents an energy loss of 105 MBtu, or about 20 percent of the steam energy delivered from that boiler plant. This result is significant but would have to be compared to the installation and maintenance costs of condensate line piping in order to determine the cost effectiveness of maximizing returned condensate.

Replacement Pipe Options

The review of commercial literature as well as discussions with select manufacturers of specialty piping did not identify any new materials for condensate piping. Use of stainless steel piping for condensate return could eliminate the corrosion problem but not at an affordable price. For most other specialty piping material such as polyethylene and polyethylene lined pipe, the limiting factor is a 200°F temperature exposure. If we consider live steam exposure from steam traps, this material has no advantage over FRP. Even polytetrafluoroethylene (PTFE) lined piping is not a workable solution despite PTFE's upper temperature limit of 450°F. Steam permeates through the PTFE liner and causes the liner to delaminate and collapse (Ref 17). This sort of lined piping is comparable in cost to stainless steel piping and offers no real advantage even when isolating the steam trap from the condensate return line through the use of hot wells.

Repair Options

Coatings. The literature review resulted in the identification of two coating developments that, upon further research, proved unsuitable to a condensate return piping system. The first coating development was a phenolic coating that is projected to provide a 10 percent improvement in service life. The Army, at their Civil Engineering Research Laboratory

(CERL), has successfully taken a phenolic coating developed by Heresite Protective Coatings of Manitiowoc, Wisconsin, and applied it to short sections of steam condensate return line within the boiler room (Ref 18). Although evaluation is at the second year of a 10-year trial, the coating has demonstrated a reduction in corrosion. A similar success has been achieved using this coating on domestic hot water heat exchangers to improve coil efficiency through reduction of corrosion and scale. The single drawback to this process is the method of application, requiring an oven bake to cure. This application process is not practical for long pipe sections, and it is certainly not feasible for field restoration of condensate return line piping.

The other coating development is an epoxy lining from the Naval Research Laboratory (NRL) primarily for restoration of shipboard piping for uses such as potable water. Unlike the phenolic coating, this epoxy coating can be applied in the field (Ref 19) to steel and copper piping. The single disadvantage of this coating is its temperature limitation of hot distilled water at 200°F. For low temperature condensate piping systems isolated from accidental steam exposure, this coating process may be advantageous as a means of reducing corrosion. Because steel is anodic, any defects in the coating would lead to localized corrosion pitting, but this would be no more severe than if the pipe were untreated (Ref 20).

Sliplining. The literature review also reported several variations of trenchless pipeline rehabilitation techniques using plastic materials. Under the Construction Productivity Advancement Research (CPAR) program, the U.S. Army Corps of Engineers participated in a state-of-the-art review on trenchless pipeline rehabilitation (Ref 21). The advantages and disadvantages of several methods were discussed. Each method involved some variation of the process, however, for this investigation, the various methods were grouped under the common terminology "sliplining."

The sliplining method involves insertion of a new pipe of smaller diameter into the existing pipe where the annulus between the old and new pipe is usually grouted. The process is economical over new pipe replacement for underground systems because there is only a minimal requirement to dig trenches. Access to the pipeline requiring sliplining can be at discrete locations so as not to disrupt the landscape and normal surface activities. Though trenchless techniques are typically applied to sewer repairs, other utilities such as water, natural gas, electricity, and telecommunications have benefited from the techniques (Ref 22).

The practice of sliplining has been applied to a variety of pipe sizes and piping media, however, there is no reported use for condensate return piping. The primary reason for not using this pipe rehabilitation technique is a temperature limitation. The pipe lining material used in this technique can be one of several unreinforced polymers, generally polyvinylchloride (PVC) or polyethylene (PE). Neither material is suitable for live steam exposure and would rate no better than the epoxy coating technique previously described. Further, there is a significant difference in thermal expansions of this pipe compared to steel pipe. As an example for equivalent diameter pipes, for one mile of PE pipe inserted at 25°F with an operating temperature of 100°F, the steel pipe expands 2.5 feet and the PE pipe expands 43.5 feet. For this reason, reinforced thermosetting resins which have a thermal expansion coefficient closer to that of steel have been suggested over unreinforced polymer liner materials (Ref 23).

Conversion to Hydronic Heating Systems

When looking at a central plant required to support clean steam requirements for ships at port, a common reason for not returning condensate back to the boiler is because the condensate is contaminated, either from leaks into the steam system or from corrosion products from poor condition condensate return line piping. In both cases, an attentive maintenance program can minimize these effects. However, given past maintenance trends, an alternative approach seems reasonable.

Converting portions of the boiler plant load from steam to hydronic heating can reduce central plant steam requirements to process steam and clean steam for ships. Other general heating users can be supplied hot water to meet their needs. The steam to water heat exchanger would be located at the central boiler plant to provide convenient maintenance and to reduce the lengths of condensate return lines. A closed circuit low temperature hot water (LTHW) or a high temperature hot water (HTHW) district heating system would serve the needs of the heating users while maximizing condensate return to the boiler.

Many European communities employ LTHW and HTHW district heating with great success. Advantages of these completely closed circuit systems include minimal corrosion and less restrictions on distribution piping layout and elevations. It would seem that the elimination of the failure potential of numerous steam traps (and trap maintenance) is all that the owner of a district steam heating system needs to hear to support a hydronic system.

Though this investigation did not have the opportunity to examine actual conversion of district steam to hydronic heating, the literature reports very encouraging results for conversions of low pressure steam heating systems on older multi-family (five-plus units) and small commercial buildings. In one report, "energy savings ranged from 13 to 39 percent of weather-normalized total gas use, with a median of 27 percent" and a "payback of about nine years" (Ref 24). The authors point out that the conversion of two pipe steam systems was easier because the existing distribution piping could be used.

It is reasonable, based on popular European usage and the ability to convert steam systems to hydronic systems, to consider hydronic systems for Navy facilities. The use of hydronic district heating would be particularly applicable if boiler replacement or district expansion were in the planning. In both cases, the conversion cost may be absorbed into the overall cost. If similar energy savings and payback periods can be realized, the additional maintenance savings in manpower and fiscal resources would further justify the expenditure.

CONCLUSIONS

Specifically, the search for a durable material to replace existing materials used for condensate return piping was unsuccessful. Improvements to the reliability and maintainability of condensate return lines can be accomplished through stricter adherence to existing installation specifications and operating procedures. The following conclusions have been drawn as a result of this investigation:

1. The decision to return condensate to the boiler is largely an economic one. For this reason, the expense of stainless steel piping is not justifiable even though it is available and it

provides good corrosion protection. Along with the many site factors, the economic decision needs to consider national energy efficiency goals and conservation of environmental resources. In all cases where condensate return is economical, boiler water treatment should be the first practice for mitigating corrosion effects. Given clean steam requirements at facilities with Navy ships in port, the treatment of contaminated condensate (condensate not meeting clean boiler water requirements) may not be economical and so justify disposal of the condensate.

2. FRP is an acceptable piping material for low pressure steam systems when installed according to guidance provided in Military Specification MIL-P-28584B - Pipe and Pipe Fittings, Glass Fiber Reinforced Plastic, Adhesive Bonded Joint Type, for Condensate Return Lines (Ref 11) and in MIL-HDBK-1003/8A - Exterior Distribution of Steam, High Temperature Water, Chilled Water, Natural Gas, and Compressed Air (Ref 4). The use of FRP piping has fallen out of favor as a low cost substitute for steel piping in condensate return systems because of piping failures. FRP piping must not be directly connected to steam traps. Given that there is not a current DOD approved vendor for FRP piping systems, the development of more specific guidance, as in the form of an NFGS, is unnecessary.

3. The current process for using DOD approved system suppliers for conduit and piping products, albeit primarily for Class A and B installations sites, is an effective method to ensure installed systems meet all government requirements for system installation, operation, and maintenance. The DOD Committee on Heating and Cooling Exterior Distribution Systems is successfully working toward improved piping systems, including condensate return piping, and is accomplishing this through participation by the Army, Navy, and Air Force as well as industry representatives.

4. The use of schedule 80 steel piping for condensate return lines remains the best choice, in terms of availability and cost, over the materials considered in this investigation. The other piping materials considered were FRP, polymer lined steel, and stainless steel. The susceptibility of steel piping to corrosion is effectively mitigated by an aggressive boiler water treatment program. Unlike plastic piping or plastic lined piping, steel piping is appropriate for direct connection to steam traps, and when properly sized is not limited by temperature or pressure exposures.

5. The in-situ pipeline repair techniques of epoxy coating and sliplining are not suited to all condensate return lines repairs. For low temperature condensate piping systems isolated from accidental steam exposure, both processes may be advantageous and the decision to repair must be an economic one. These repair processes would not be applicable for high temperature steam piping systems with condensate temperatures over 200°F, or on any system with the possibility of live steam exposure. If condensate temperature was effectively controlled through use of a hot well, then the epoxy coating technique would be more advantageous than sliplining because the flow capacity of the pipe is not reduced by the liner.

6. Conversion of steam heating loads to hot water (hydronic) heating represents a viable alternative to continued steam distribution for facilities considering boiler system replacement or

expansion. The closed circuit hydronic system, with its long history of success in the European community and reported energy savings over steam distribution heating, is easier to maintain than a steam system primarily because steam traps are not used.

RECOMMENDATIONS

The following recommendations are provided based on the investigation results and conclusions drawn:

1. Provided that returning condensate to the boiler is economical based on the factors presented in this report, the life expectancy of the condensate piping can be extended by aggressive boiler water treatment. The Army's Technical Note No. 86-3 on the Use of Diethylaminoethanol, Morpholine, and Cyclohexylamine for Condensate Return Line Corrosion Prevention (Ref 15) should be circulated to Navy boiler plant operators as a guide for proper boiler water treatment.

2. Any Navy facility considering steam boiler system replacement or expansion should consider converting all or part of the heating load over to a hydronic system. An economic analysis should be performed to determine if the payback period is 10 years or less. Considering that there is little data available on the economics of converting a distributed steam heating system to hydronic heating, the early cases should be well documented for later analysis of achieved energy efficiency and cost payback period.

3. The DOD Committee on Heating and Cooling Exterior Distribution Systems list of technology issues associated with district heating systems is recommended as guidance for Navy laboratory participation. Investigations of Committee selected technologies in concert with other DOD services will achieve the most value for the money spent. Navy participation on this tri-service committee will ensure that Navy needs are factored into any investigations, particularly since the Navy has a unique requirement for clean steam for ship use at port.

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16. Henry Studebaker. Personal communication, Naval Facilities Engineering Service Center, Port Hueneme, CA, 23 Jan 1995.

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18. Construction Engineering Research Laboratories (U.S.). Interim Report FM-94/08: Field test results of corrosion-resistant coatings for carbon-steel steam condensate return lines. USACERL, Champaign, IL, Apr 1994.

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21. D.T. Iseley, M. Najafi, and R.D. Bennett. "Trenchless pipeline rehabilitation with plastic materials," Buried Plastic Pipe Technology, vol 2, ASTM STP 1222, Dave Eckstein, Ed., American Society for Testing and Materials, Philadelphia, PA, 1994.

22. H. Gerard Schwartz Jr. "Trenchless technologies offer viable options," American City and County, Oct 1989, pp 30-33.

23. Benant E. Fruck. "Plastic liners for pipeline rejuvenation," in Proceedings of Interpipe '84 Conference, 1984.

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Duggan, Robert B. and Fredric R. Shaffer (1993). "Retrofitting for energy savings with hydronic heating systems," Specifying Engineer, Jun 1993.

Mizell, Lee and Larry J. Petroff (1993). "Sliplining: Design and installation considerations for polyethylene pipe," Pipeline Infrastructure II, Mark B. Pickell, Ed., American Society of Civil Engineers, New York, NY, Aug 1993.

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Sandstrum, Steve D. (1988). "Pipeline rehabilitation with polyolefin pipe," Pipeline Infrastructure, Bruce A. Bennett, Ed., American Society of Civil Engineers, New York, NY, Jun 1988.

Stethem, W.C. (1994). "Single-pipe hydronic system design and load-matching pumping," ASHRAE Transactions: Symposia, American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Atlanta, GA, 1994.

Appendix A

LITERATURE SEARCH RESULTS

Condensate Return Line Technology **10 January 1995**

DIALOG(R)File 103: Energy SciTec(c)format only 1995 Knight-Ridder Info. All rts. reserv.
03744710 GRA-94-70391; EDB-94-160676
Title: *Field test results of corrosion-resistant coatings for carbon-steel steam condensate return lines. Interim report.*
Authors/editors: Hock, V.F.; Cardenas, H.; and Myers, J.R.
Corporate source: Army Construction Engineering Research Lab., Champaign, IL
Publication date: Apr 94 (31 p)
Report number: AD-A-283208/7/XAB

DIALOG(R)File 103: Energy SciTec(c)format only 1995 Knight-Ridder Info. All rts. reserv.
03685104 GB-94-051425; EDB-94-101070
Title: *Electric heaters for process applications.*
Authors: Armstrong, R. (Chemtec BV (United States))
Source: Hydrocarbon Technology International (United Kingdom) v 1993 issue.
Coden: XZ289I
Publication date: 1993 p 88-90

DIALOG(R)File 103: Energy SciTec(c)format only 1995 Knight-Ridder Info. All rts. reserv.
03352052 NOV-92-030410; EDB-92-114809
Title: *Replacement projects, risk analysis.*
Authors: Mycick, C.E.; Van Dyke, H.J.; and Mayer, G.R. (Bechtel, Inc., San Francisco, CA)
Title: *Piping design handbook.*
Author/editor: McKetta, J.J. (University of Texas at Austin, Austin, TX)
Publisher: New York, NY, Marcel Dekker Inc.
Publication date: 1992 p 1105-1111 (1198 p)
ISBN: 0-8247-8570-3

DIALOG(R)File 103: Energy SciTec(c)format only 1995 Knight-Ridder Info. All rts. reserv.
03351931 NOV-92-030412; EDB-92-114688
Title: *Flashing steam condensate.*
Author: Ruskin, R.D.
Title: *Piping design handbook*
Author/editor: McKetta, J.J. (University of Texas at Austin, Austin, TX
Publisher: New York, NY, Marcel Dekker Inc.
Publication date: 1992 p 405-410 (1198 p)
ISBN: 0-8247-8570-3

Condensate Return Line Technology **10 January 1995**

DIALOG(R)File 8:Ei Compendex*Plus(TM)(c) 1994 Engineering Info. Inc. All rts. reserv.
03788720 E.I. No: EIP93121162292
Title: *Film thickness measurement with an ultrasonic transducer.*
Authors: Lu, Qing; Suryanarayana, N.V.; and Christodoulu, Christodoulous
Corporate source: Michigan Technological Univ, Houghton, MI
Source: Experimental Thermal and Fluid Science v ol 7, no. 4, Nov 93, p354-361
Publication year: 1993
CODEN: ETFSEO ISSN: 0894-1777

DIALOG(R)File 8:Ei Compendex*Plus(TM)(c) 1994 Engineering Info. Inc. All rts. reserv.
03714805 E.I. No: EIP93091086108
Title: *Strategic plan for a successful flow-accelerated corrosion program.*
Authors: Chexal, Bindi; Mahini, Ramtin; Munson, Doug; Horowitz, Jeff; Randall, Gus; and Shevde, Vishwas
Corporate source: Electric Power Research Inst, Palo Alto, CA
Conference title: 1993 Pressure Vessels and Piping Conference.
Conference location: Denver, CO
E.I. Conference no.: 19192
Source: Codes and Standards in A Global Environment, American Society of Mechanical Engineers, Pressure Vessels and Piping Division (Publication)
PVP v 259 1993. Publ by ASME, New York, NY, p 201-208
Publication year: 1993
CODEN: AMPPD5 ISSN: 0277-027X ISBN: 0-7918-0986-2

DIALOG(R)File 8:Ei Compendex*Plus(TM)(c) 1994 Engineering Info. Inc. All rts. reserv.
03676216 E.I. No: EIP93071019712
Title: *Increasing steam turbine efficiency and reducing downtime by removing water soluble deposits with water injection.*
Authors: Roberts, Daniel E.; Felten, John; and Capps, Dennis
Corporate source: Coors Brewing Co., Golden, CO
Conference title: 1993 Industrial Power Conference
Conference location: Denver, CO
E.I. Conference no.: 18670
Source: American Society of Mechanical Engineers, Power Division, (Publication)
PWR v 20 1993. Publ by ASME, New York, NY, p 41-47
Publication year: 1993
CODEN: AMEPEJ ISBN: 0-7918-0679-0

Condensate Return Line Technology **10 January 1995**

DIALOG(R)File 8:Ei Compendex*Plus(TM)(c) 1994 Engineering Info. Inc. All rts. reserv.
03613666 E.I. No: EIP93030737985
Title: *Response of NPP circulation circuit elements to abrupt changes in pressure.*
Authors: Syzarev, V.D.; Baranov, I.M.; Korotchenko, G.I.; Prostyakov, V.V.; and Menyailov, A.I.
Corporate source: Inst of Power Engineering, Moscow, Russia
Conference title: Winter Annual Meeting of the American Society of Mechanical Engineers
Conference location: Anaheim, CA
E.I. Conference no.: 17663
Source: FSI/FIV in Cylinder Arrays in Cross-Flow American Society of Mechanical Engineers, Heat Transfer Division, (Publication) HTD v 230 1992.
Publ by ASME, New York, NY, p 261-272
Publication year: 1992
CODEN: ASMHD8 ISSN: 0272-5673 ISBN: 0-7918-1078-X

DIALOG(R)File 25: CLAIMS(R)/US Patents Abs(c) 1995 IFI/Plenum Data Corp. All rts. reserv.
2036552 3021605
M/Monogroove Liquid Heat Exchanger
Inventors: Brown Richard F (U.S.) and Edelstein Fred (U.S.)
Assignee: United States of America NASA Administrator of Assignee Code: 86504

Reassigned

	Patent Number	Issue Date	Application Number	Application Date
Patent:	US 4917173	900417	US 271266	881115
Priority Applic:			US 271266	771115

Sliplining **27 January 1995**

3/6/1 (Item 1 from file: 6)
1171047 NTIS Accession Number: PB86-130192/XAB
Title: *Insituform and Other Sewer Rehabilitation Techniques.*
(Final rept. Nov 77-Dec 83)
NTIS prices: PC A07/MF A01

3/6/2 (Item 1 from file: 103)
01657246 EDB-85-164026
Title: *Sliplining a 42-in. cast iron gas main at Southport using an 800mm PE pressure pipe.*

3/6/3 (Item 1 from file: 14)
0154312
Title: *Strength of HDPE pipes for the renovation of pipelines by sliplining.*

Sliplining **27 January 1995**

3/6/4 (Item 1 from file: 8)
03940182
Title: *Trenchless pipeline rehabilitation with plastic materials.*
Conference title: Proceedings of the Symposium on Buried Plastic Pipe Technology: 2nd Volume.

3/6/5 (Item 2 from file: 8)
03705486
Title: *Microtunneling of vitrified clay pipe in the United States.*
Conference title: Proceedings of the International Conference on Pipeline Infrastructure II.

3/6/6 (Item 3 from file: 8)
03705453
Title: *Trenchless diversity fuels growth of construction activities.*
Conference title: Proceedings of the International Conference on Pipeline Infrastructure II.

3/6/7 (Item 4 from file: 8)
03705452
Title: *Sliplining: Design and installation considerations for polyethylene pipe.*
Conference title: Proceedings of the International Conference on Pipeline Infrastructure II.

3/6/8 (Item 5 from file: 8)
03690677
Title: *Big competition for small bore markets.*

3/6/9 (Item 6 from file: 8)
03067301
Title: *Rehabilitation of decant structure for coal slurry impoundment in Ohio.*
Conference title: Proceedings of the Symposium on Environmental Management for the 1990's.

3/6/10 (Item 7 from file: 8)
03066371
Title: *Large diameter sewer rehabilitation by sliplining in Florida.*
Conference title: Symposium on Buried Plastic Pipe Technology.

3/6/11 (Item 8 from file: 8)
03005099
Title: *Sliplining rescues sewers and a small budget.*

3/6/12 (Item 9 from file: 8)
02866785
Title: *Trenchless technologies offer viable options.*

Sliplining **27 January 1995**

3/6/13 (Item 10 from file: 8)
02842955
Title: *Pipeline renovation.*

3/6/14 (Item 11 from file: 8)
02738667
Title: *Sliplining with PE pipe repairs sewer lines.*

3/6/15 (Item 12 from file: 8)
02678270
Title: *Sliplining with ductile iron pipe.*
Conference title: Pipeline Infrastructure Proceedings.

3/6/16 (Item 13 from file: 8)
02678255
Title: *Pipeline rehabilitation with polyolefin pipe.*
Conference title: Pipeline Infrastructure Proceedings.

3/6/17 (Item 14 from file: 8)
02599544
Title: *Sliplining for sewer rehabilitation.*

3/6/18 (Item 15 from file: 8)
02338810
Title: *Rolling down for relining.*

3/6/19 (Item 16 from file: 8)
02297845
Title: *Failing sewer saved by jacking pipe through it.*

3/6/20 (Item 17 from file: 8)
02118630
Title: *Sliplining a 137 year old, 20" diameter cast iron water main.*
Conference title: Plastics for Pipeline Renovation and Corrosion Protection in UK and Overseas.

3/6/21 (Item 18 from file: 8)
01682933
Title: *Plastic liners for pipeline rejuvenation.*
Conference title: Interpipe '84, 12th International Pipeline Technology Conference & Exhibition.

Sliplining **27 January 1995**

3/6/22 (Item 19 from file: 8)
01410977
Title: Sewers: *Repairing beats replacing.*

3/6/23 (Item 20 from file: 8)
00530492
Title: *Seal manholes tight.*

Hydronic Heating **1 March 1995**

4/6/1 (Item 1 from file: 103)
03532751 EDB-93-105232
Title: *Energy savings and field experience from converting steam-heated buildings to hydronic heat.*
Title: ASHRAE transactions 1993. Part 1

4/6/2 (Item 2 from file: 103)
02316490 CANM-89-001010; EDB-89-062231
Title: *Understanding hydronic heating systems.*

4/6/3 (Item 3 from file: 103)
01468845 EDB-84-166651
Title: *Retrofitting for energy savings with hydronic heating systems.*

4/6/4 (Item 1 from file: 8)
03684879
Title: *Energy savings and field experience from converting steam-heated buildings to hydronic heat.*
Conference title: Proceedings of the 1993 Winter Meeting of ASHRAE Transactions. Part 1.

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01397566
Title: *Retrofitting for energy savings with hydronic heating systems.*

4/6/6 (Item 3 from file: 8)
00554482
Title: *Beneficial uses of waste heat from steam electric power plants.*

4/6/7 (Item 4 from file: 8)
00443520
Title: *Influence of adiabatic air moistening on the energy consumption of air conditioning plants.*
Title: *Einfluss der adiabaten luftbefeuchtung auf den energieverbrauch von klimaanlagen.*

Hydronic Heating **1 March 1995**

7/6/1 (Item 1 from file: 103)
03735820 EDB-94-151786
Title: *Control of multizone hydronic radiant floor heating systems.*
Title: ASHRAE transactions: Volume 100, Part 1

7/6/2 (Item 2 from file: 103)
03735808 EDB-94-151774
Title: *Single-pipe hydronic system design and load-matched pumping.*
Title: ASHRAE transactions: Volume 100, Part 1

7/6/3 (Item 3 from file: 103)
03735800 EDB-94-151766
Title: *Why consider a primary-secondary hydronic pumping system.*
Title: ASHRAE transactions: Volume 100, Part 1

7/6/4 (Item 4 from file: 103)
03678444 FI-94-003233; EDB-94-094410
Title: *An experimental study on transient thermal behaviour of new hydronic radiant floor heating systems.*
Title: Indoor Air '93. Ventilation

7/6/5 (Item 5 from file: 103)
03647593 CHF-94-0G4298; EDB-94-063559
Title: *On saving pumping power in hydronic thermal distribution systems through the use of drag-reducing additives.*

7/6/6 (Item 6 from file: 103)
03587729 EDB-94-003695
Title: *European hydronic heating concepts for the American market of today.*
Conference title: Proceedings of the 1991 Oil Heat Technology Conference and Workshop

7/6/7 (Item 7 from file: 103)
03532970 EDB-93-105451
Title: *Hydronic radiant cooling: Overview and preliminary performance assessment.*

7/6/8 (Item 8 from file: 103)
03532744 EDB-93-105225
Title: *Heat emission rates of hydronic terminal elements and their relationship to heating cost allocation devices.*
Title: ASHRAE transactions 1993. Part 1

Hydronic Heating **1 March 1995**

7/6/9 (Item 9 from file: 103)
03459551 EDB-93-038427
Title: *Multi-source hydronic heat pump systems.*
Title: *Innovative energy design for the '90s.*

7/6/10 (Item 10 from file: 103)
03414636 GRA-92-13240; EDB-92-177393
Title: *Gas laboratory house hydronic-heating test results.*
Topical report, November 1990-April 1991.

7/6/11 (Item 11 from file: 103)
03339974 GRA-92-42521; EDB-92-102731
Title: *Development of a hydronic Btu meter for multi-family applications.*
Final report, March 1, 1990-April 30, 1991

7/6/12 (Item 12 from file: 103)
02961005 NOV-90-040086; EDB-90-178248
Title: *Low-rise residential hydronic heating systems.*

7/6/13 (Item 1 from file: 6)
1507681 NTIS Accession Number: PB91-130294/XAB
Title: *Development of a hydronic BTU meter for multi-family applications.*
Final Report January 1988-October 1989
NTIS Prices: PC A04/MF A01

7/6/14 (Item 1 from file: 8)
03903277
Title: *Multivariable integral control of hydronic heating systems.*

7/6/15 (Item 2 from file: 8)
03812046
Title: *Designing and commissioning variable flow hydronic systems.*

7/6/16 (Item 3 from file: 8)
03431220
Title: *Feasibility study of the use of drag-reducing additives to reduce pumping power in hydronic thermal distribution systems.*
Conference title: Winter Annual Meeting of the American Society of Mechanical Engineers.

7/6/17 (Item 4 from file: 8)
03383150
Title: *Converting constant-speed hydronic pumping systems to variable-speed pumping.*
Conference title: ASHRAE Winter Meeting - Technical Papers.

7/6/18 (Item 5 from file: 8)
03323174
Title: *In-slab hydronic heating systems warm rooms indoors, melt snow and ice outdoors.*

7/6/19 (Item 6 from file: 8)
03080927
Title: *Control of a simulated dual-temperature hydronic system using a neural network approach.*
Conference title: 1990 Annual Meeting of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Technical and Symposium Papers.

Appendix B

UNDERGROUND HEAT DISTRIBUTION SYSTEMS (UHDS) COMMITTEE TECHNOLOGY TOPICS

This is a prioritized listing of research or development efforts resulting from the 1993 Annual Research Review Workshop on Underground Heat Distribution Systems (UHDS) held 11 August 1993 at Norfolk Naval Station in Norfolk, Virginia. In attendance were representatives from both design and O&M from the Army, Navy, Air Force, Veterans Administration, and the Department of Housing and Urban Development. It was agreed upon that these efforts were currently needed in order to address the current problems associated with underground heat distribution systems being experienced within the DOD. It was decided that the efforts that are currently underway or programmed should be rated "1A" with all other proposed work being ranked in numerical order. The research and/or development areas are:

1A. Survey of Drainable/Dryable UHDS

1A. Standard Life Cycle Cost Analysis Procedures for HDS

1A. Experimental Heat Loss Measurement from Wet Conduit Piping

1A. Isolation Flange Kits and Cathodic Protection

1A. Heat Loss Measurements at Ft. Jackson and Ft. Irwin

1A. O&M and Repair Costs at Ft. Jackson, Ft. Riley, and Ft. Bragg

1A. Heat Distribution Systems Database

1A. Maintenance Management System for Heat Distribution Systems

1A. Computer Aided Design and Operation of HDS

1. Analysis of UHDS Survey

2. Optimization of Standard Shallow Trench Design

3. ECIP Justification for HDS

4. Low Temperature Hot Water Piping/Systems

5. Temperature Limitations of Non-metallic UHDS Materials
6. Water Spread Limiting Systems on Class A Sites
7. Operation/Supply Contract Specifications
8. Waterproofing of Manholes from Water Intrusion
9. Materials and Design Issues of Gland Seals
10. Insulation Testing (K-Factor and Chloride Content)
11. Sump Pump Guide Specification Improvement
12. High Reliability Thermostatic Steam Trap Investigation
13. Practical Leak Detection for Existing and New UHDS
14. Improved Inspection of New Construction and Qualification of Craft Workers
15. Improved Procurement and/or Detailed Guide Specification
16. Pressure Testing of New Systems
17. Investigation of Powder Insulation

Appendix C

CONDENSATE RETURN PIPING DESIGN

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) in their 1992 Systems and Equipment Handbook (Ref 2) lists the following considerations for condensate return piping design:

1. Flow in the return line is two-phase, consisting of steam and condensate.

2. Pitch return lines downward in the direction of the condensate flow at 0.5 inch per 10 feet to ensure prompt condensate removal.

3. Insulate the return line well, especially where the condensate is returned to the boiler or the condensate enthalpy is recovered.

4. Where possible and practical, use heat recovery systems to recover the condensate enthalpy.

5. Equip dirt pockets of the drip legs and strainer blowdowns with valves to remove dirt and scale.

6. Install steam traps close to drip legs and strainer blowdowns for inspection and repair. Servicing is simplified by making the pipe sizes and configuration identical for a given type and size of trap.

7. When elevating condensate to an overhead return, consider the pressure at the trap inlet and the fact that it requires approximately 1 psi to elevate condensate 2 feet.

Appendix D

EXAMPLE OF ENERGY LOSS CALCULATIONS

Example:

Bldg. 160 Boiler Plant (1990 Data)
MCRD Beaufort
Charleston, SC

Usage: 80 percent Heating
20 percent Process

Delivered 528.981 MBtu of steam at conditions of 345°F at 125 psi

Enthalpy of Evaporation (h_{fg}) = 875.0 (Btu/lb_m)
Enthalpy of Saturated Liquid (h_f) = 315.8 (Btu/lb_m)
Specific Volume of Saturated Liquid (v_f) = 0.01793 (ft^3/lb_m)

Mass of saturated steam (lb_m) = Total energy delivered (Btu) / Enthalpy h_{fg} (Btu/lb_m)
= $528.981(10^6) / 875.0$
= 604,549.7 (lb_m)

After condensing: $m_g = m_f$

Volume of liquid (ft^3) = Mass of liquid (lb_m) x Specific Volume of Liquid v_f (ft^3/lb_m)
= 604,549.7 (lb_m) x 0.01793 (ft^3/lb_m)
= 10,839.6 ft^3 of liquid

Or,
= 81,085 gallons of condensate

For a 75 percent condensate loss, less the 20 percent of process steam that is not returnable, 55 percent of available condensate represents lost energy savings potential.

Volume of available condensate (gal) = Volume of liquid (gal) by percent available (%)
= 81,085 gallons x 0.55
= 44,597 gallons

Or,

= 5961.8 ft^3

Energy lost (Btu) = Mass of saturated steam (lb_m) x Enthalpy h_f (Btu/lb_m)

= ($5961.8\ ft^3 / 0.01793\ (ft^3/lb_m)$) x $315.8\ (Btu/lb_m)$

= 105.0 MBtu

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MCLB / PWO, BARSTOW, CA
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NASA HDQTRS / WICKMAN, WASHINGTON, DC
NAVAMPHIBBASE / CODE N491, NORFOLK, VA
NAVCOSSYSCEN / CODE 7410EH, PANAMA CITY, FL
NAVFACENGCOM / CODE 03R (BERSSON), ALEXANDRIA, VA
NAVSHIPYD / CODE 453-HD, PORTSMOUTH, VA
NAVSTA / CODE 183, CHARLESTON, SC
NAVSTA / CODE 610, SAN DIEGO, CA
NAVSTA / CODE 634, SAN DIEGO, CA
NAVSTA TREASURE ISLAND / CODE 83, SAN FRANCISCO, CA
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NAVSUBBAS BANGOR / CODE 831, SILVERDALE, WA
NAVSUPCEN / CODE 73, NORFOLK, VA
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NAVTRASTA / CODE 523, ORLANDO, FL
NAVUSEAWARENGSTA / CODE 073, KEYPORT, WA
NAVWEAPSTA / CODE 09202, CONCORD, CA
NAVWEAPSTA / CODE 0923, SEAL BEACH, CA
NCCOSC / CODE 811, SAN DIEGO, CA
NSGA / CODE 90, SONOMA, CA

OCNR / CODE 1114SE, ARLINGTON, VA
ROICC / CODE 05 (MARK KEAST), FPO AE
ROICC / CODE R-30DM, CHARLESTON, SC
ROICC / CODE RS4, FPO AE
ROICC NAVBASE / CODE 30BD, CHARLESTON, SC
SCIENCE VU RESEARCH / JOHN D CUNNINGHAM, EAST SWANZEY, NH
SOUTHNAVFACENGCOM / CODE 403 (GADDY), NORTH CHARLESTON, SC
STATE HOUSE / OFFICE OF ENERGY RESOURCES, AUGUSTA, ME
TENNESSEE / ENERGY DIV, NASHVILLE, TN
UNIV OF CALIFORNIA / ENERGY ENGR, DAVIS, CA
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USDA / FOR SVC REG 1, TECH ENGRS, MISSOULA, MT
USDA / FOR SVC REG 2, ENGR TECH STAFF, LAKEWOOD, CO
USDA / FOR SVC REG 3, ENGR TECH STAFF, ALBUQUERQUE, NM
USDA / FOR SVC REG 4, TECH STAFF, OGDEN, UT
USDA / FOR SVC REG 8, TECH ENGRS, ATLANTA, GA
USDA / FOREST EXPER STA, ST PAUL, MN
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